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Enhancing Nutritional and Functional Properties of Plant-Based Meatballs: A Study on *Kepok* Banana Flower, Brown Lentils, and Wheat Gluten

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Abstract

Interest in meat substitutes has grown in recent years as consumers seek healthier options. However, many products still face limitations, either in texture or in nutritional balance. *Kepok* banana flower (KBF), with its fibrous structure, has the potential to mimic meat texture, though its protein content is relatively low. Brown lentils can enhance protein content, while high-protein binders such as isolated soy protein (ISP) and wheat gluten (WG) improve texture and structural integrity. This study aimed to determine the optimum ratio of minced KBF (MKBF) to brown lentil paste (BLP) and to evaluate binder formulations for nutrient-rich plant-based meatballs. The research was conducted in two stages. First, eight MKBF:BLP ratios (100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70) were tested for protein content, cooking yield, and lightness (L*), identifying 40:60 as optimal. Second, the 40:60 blend was incorporated into five binder formulations: F0 (commercial reference), F1 (0% WG + 10% ISP), F2 (15% WG + 3% ISP), F3 (20% WG + 3% ISP), and F4 (25% WG + 3% ISP). Analyses included water-holding capacity (WHC), total dietary fiber (TDF), texture profile analysis, and sensory evaluation. The 40:60 ratio yielded 10.24±0.08% protein, 105.68±2.81% cooking yield, and 47.20±0.15 L*. The F4 showed the highest WHC (52.94±9.14%) and TDF (5.99±0.06%), with a hardness of 516.51±31.62 g, chewiness of 353.28±21.66 Nmm, and springiness of 0.87±0.02 mm. Sensory analysis showed that F4 was most comparable to F0. These results suggest that a 40:60 MKBF and BLP combined with WG and ISP produces consumer-acceptable plant-based meatballs with high protein and dietary fiber.

Keywords: meat substitute; plant-based protein; pulses; sensory evaluation; texture profile analysis

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INTRODUCTION

Meatballs are processed meat products shaped and cooked from cattle flesh combined with starch, spices, other food components, and approved food additives (Tiven and Simanjorang, 2025). In Indonesia, ground beef is the most commonly used type of meat for making meatballs. Meat is a protein source in meatballs, and its high protein content adds to the meatballs' chewy texture (Amalia et al., 2022; Yie et al., 2023).

Total greenhouse gas emissions have been continuously rising over the past century. Meat-eaters report producing higher dietary greenhouse gas emissions compared to those following a vegan diet. From a sustainability perspective, encouraging consumers to replace a portion of their animal protein intake with plant-based options is a favorable approach. Food manufacturers have already developed several plant-based protein products that mimic the

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texture of meat. Some of these products have already entered the market, although consumer acceptance still varies depending on eating habits and preferences (Bryant, 2022; Xavier et al., 2025). Numerous studies have developed a diverse range of plant-based ingredients by incorporating various ingredients, such as legumes and mushrooms (Bakhsh et al., 2021; Prakash et al., 2023). However, the acceptance of meat substitutes still needs to be higher in Indonesia.

Many plant-based products are now available in the market, but meat analogues still have some apparent shortcomings. The protein they contain often lacks essential amino acids, which lowers its nutritional quality compared to animal protein. In terms of texture, these products are usually drier and less juicy, and they do not quite match the fibrous, elastic structure of actual meat. Using fibrous ingredients can also make the product less firm or even crumbly, which lowers consumer appeal. Due to these limitations, it becomes necessary to combine different plant-based ingredients that can balance texture and increase the overall nutritional profile of the product (Juhrich et al., 2025; Khezerlou et al., 2025).

Kepok banana flower/KBF (*Musa paradisiaca* L.) has a fibrous structure, making it suitable for meat-like food products. Kartikaningsih et al. (2021) reported the use in high-fiber formulations. Thagunnaa et al. (2023) showed that the banana flower of the *Paradisiaca* cultivar contains a high amount of total dietary fiber (TDF) (5.74%) and a low amount of fat and protein (0.6% and 1.62%, respectively). Thagunnaa's study also aligns with the study by Farida and Rawiniwati (2021) which utilized a 20:80 ratio of banana flower to oyster mushroom. The addition of oyster mushrooms resulted in a high protein content (10.52%) and 5.31% crude fiber content. The protein content exceeds the meatball quality requirement of 9% as stated in Indonesian National Standard 3818:2014 (Widati et al., 2021). The high protein content of plant-based products helps to compensate for the lower nutritional value of plant protein, which lacks some essential amino acids (Day et al., 2022). An additional protein source addresses the protein deficiency in banana flower plant-based meatballs. One additional source of protein is lentils. Brown lentils have a higher protein content of 18% compared to red and green lentils, which have a protein content of 9.6% (Chelladurai and Erkinbaev, 2020). In comparison to green lentils, brown lentils are better at retaining shape and will not turn soft after cooking (Sonmezler et al., 2025).

To achieve a uniform texture in plant-based products, ingredients with gel-forming abilities are essential; therefore, high-protein substances serve as texturizers (Kyriakopoulou et al., 2021). Isolated soy protein (ISP) is a widely used binder for meat products, as well as plant-based meat products such as bacon analogues (Herz et al., 2021) and plant-based sausages (Yuan et al., 2021). This research utilizes binder formulations containing wheat gluten (WG) and ISP to enhance the texture of plant-based products. The mixture of WG and ISP in the meat analogue formulation, used as a binder, created a more fibrous texture than using ISP as the binder alone, due to the high content of disulfide bonds. Besides making a better texture, WG has more economic benefits than the more expensive ISP (Devi et al., 2025).

WG can create chewy and springy textures on food products and acts as a binder and texturizer (Maningat et al., 2022). WG serves as a texturizer in burger patties and muscle-type plant-based products. Protein linking will create a three-dimensional network, resulting in a fibrous structure in plant-based products such as meat analogues, which are whole-cut or minced meat types (Kyriakopoulou et al., 2021).

Previous studies have investigated various plant-based meatball formulations using legumes and other plant proteins. However, research on the use of KBF as an ingredient, combined with pulses, particularly brown lentil, remains limited. Moreover, there has been no evaluation of the optimum ratio of minced KBF (MKBF) to brown lentil paste (BLP) that could improve both the nutritional quality and the physicochemical properties of plant-based meatballs. In addition, limited studies have optimized binder formulations to achieve a texture profile comparable to that of commercial plant-based meatballs while maintaining desirable sensory properties. Thus, this study aims to (1) determine the optimum MKBF-to-BLP ratios based on protein content, cooking yield, and lightness (L*) and (2) evaluate various binder formulations on water-holding capacity (WHC), texture profile analysis, TDF, and sensory characteristics of plant-based meatballs. Hence, the findings in this study will provide a cost-effective and nutritionally enhanced meat substitute, particularly in the production of meatballs, thereby contributing to the development of sustainable plant-based products.

MATERIALS AND METHOD

Raw materials and equipment

The materials used to make the plant-based meatballs included KBF (*Musa paradisiaca* L.) obtained from a traditional market in Tangerang, Indonesia, with specifications of 20 to 25 cm in length, dark red-brown color, and a weight of 500 to 750 g; brown lentils purchased from the online marketplace "Granology," with specifications of 4 to 5 mm in diameter and brown in color; tapioca flour ("Rose Brand"); salt ("Dolphin"); pepper ("Koepoe-Koepoe"); garlic powder ("Koepoe-Koepoe"); ISP ("Para Agribusiness"); WG ("Golden Ante"); commercial plant-based meatballs; and deionized water. The materials used for the analysis included aquadest, selenium, K_2SO_4, 96% H_2SO_4, 35% H_2O_2, 4% boric acid, 35% NaOH, 0.2 N HCl, and a mixed indicator of bromocresol green and methyl red, all of which were obtained from Smart Lab (Indonesia).

The equipment used to prepare the plant-based meatballs included a food processor, balance, basins, knives, cooking pot, stove, spoon, plastic bowl, cutting board, and drainer. The equipment used for the analysis included an analytical balance, oven, evaporating dish, glassware, desiccator, pipette, texture analyzer, Kjeldahl apparatus, heater, centrifuge tubes, centrifuge, and chromameter.

Preparation of MKBF

The preparation of MKBF followed the methods outlined by Wahab et al. (2020) with modifications. The hardened skin of the KBF peels off, the pistils detach, and the banana flowers wash until only the inner layer remains. The KBF was then boiled for 30 minutes to remove sap from banana flowers and soften the texture. The boiled KBF is then reduced in size to facilitate mixing during plant-based meatball production, resulting in the MKBF. MKBF underwent analysis to determine its moisture content, protein content, L*, and TDF.

This study analyzed moisture content by drying the sample in an oven (Memmert UNB 500), following the AOAC 925.10 method. Protein analysis followed the Kjeldahl method (AOAC 928.08) using a Buchi Kjeldahl apparatus. TDF content was assessed with the multienzyme method (AOAC 991.43) (Haritha and Bukya, 2025). The moisture, protein, and TDF values were then calculated using Equations 1, 2, and 3, respectively.

A chromameter (Konica Minolta CR-400) was used to assess the L* value of MKBF (Richirose and Soedirga, 2023). The instrument was calibrated before measurement by placing the flat tip on a white calibration plate. The L* scale ranges from 0 (black) to 100 (white).

Preparation of BLP

BLP production followed the method outlined by Alsalman et al. (2020). Brown lentils were washed and soaked for 30 minutes to ease the hull removal. The soaked brown lentils were then boiled in drinking water at 70 °C for 30 minutes, using a 1:4 lentil-to-water ratio. The boiled lentils were drained to remove excess water and subsequently blended with a food processor (Philips) to produce BLP. Moisture, protein, TDF, and L* values were analyzed using the same methods and formulas applied for MKBF.

Formulation development of plant-based meatball

The development of plant-based meatball formulation involved two stages. The first stage aimed to determine the optimum MKBF-to-BLP ratio (100:0, 90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70) in terms of protein content, cooking yield, and L*—three key parameters of nutritional value, product recovery, and visual quality. The formulation utilized the fibrous texture and fiber content of MKBF, which supported structural formation. The addition of BLP enhanced protein content and moisture retention, leading to a higher yield. A completely randomized one-factorial

$$\text{Moisture content (\%,wb)} = \frac{\text{Initial sample weight (g) - Final sample weight (g)}}{\text{Initial sample weight (g)}} \times 100\% \quad (1)$$

$$\text{TDF (\%)} = \text{Soluble dietary fiber (\%)} + \text{Insoluble dietary fiber (\%)} \quad (2)$$

$$\text{Protein content (\%)} = \frac{(\text{Volume sample (ml) - Volume blank (ml)}) \times \text{N HCl} \times 14.008 \times 6.25}{\text{Weight of sample (g)} \times 1{,}000} \times 100\% \quad (3)$$

Table 1. Plant-based meatball formulation with different ratios of MKBF:BLP

Composition	R1-R7	F1	F2	F3	F4
Plant-based ingredients (%)	100	100	100	100	100
Tapioca flour (%)	15	15	15	15	15
Salt (%)	2	2	2	2	2
Pepper (%)	0.2	0.2	0.2	0.2	0.2
Garlic powder (%)	1	1	1	1	1
WG (%)	0	0	15	20	25
ISP (%)	10	10	3	3	3

Note: R1-R7 = Formulations with eight varying ratios of MKBF:BLP. F1-F4 = Formulations using the optimum MKBF:BLP ratio of 40:60 with different combinations of binders (WG:ISP). All percentages of other materials were based on the weight of plant-based ingredients. F0 was excluded from the table since it was not prepared as part of the experimental formulations. Source: Farida and Rawiniwati (2021) with modifications

$$\text{Cooking yield (\%)} = \frac{\text{Cooked sample (g)}}{\text{Uncooked sample (g)}} \text{ x } 100\% \tag{4}$$

$$\text{WHC (\%)} = \frac{\text{Weight of water added (g) - Weight of water removed (g)}}{\text{Weight of sample (g)}} \times 100\% \tag{5}$$

design with eight levels was used to determine the effect of different MKBF-to-BLP ratios.

The second stage involved treating plant-based meatballs with the selected ratio using different binder formulations. A completely randomized one-factorial design with five levels was applied to determine the effect of binder formulations. F0, representing commercial plant-based meatballs (brand “VG”), was included as a reference for comparison. While F1 to F4 represented plant-based meatballs prepared using the optimum MKBF-to-BLP ratio with the addition of ISP and WG as follows: F1 (0% WG + 10% ISP), F2 (15% WG + 3% ISP), F3 (20% WG + 3% ISP), and F4 (25% WG + 3% ISP). These formulations aimed to balance protein functionality, texture, and practical usage levels of ISP and WG in meatballs. ISP is known for its high water-binding capacity and ability to form cohesive gels. WG has viscoelastic properties, which contribute to elasticity and a meat-like chewiness. The F2, F3, and F4 were maintained at 3% of ISP to preserve protein structure and water retention, while the WG was varied from 15 to 25% to assess its contribution to textural properties. F1 served as a control without WG to observe the independent effect of ISP. Literature and preliminary trials guided the selection of binder formulations to avoid textures that are unacceptable or gluten levels that reduce sensory appeal. Table 1 shows the formulations used.

The procedure for preparing plant-based meatballs in both stages followed the method described by Farida and Rawiniwati (2021), with modifications. The process began by weighing the ingredients listed in Table 1, followed by mixing them in a food processor (Philips). Portions of 10 g were weighed (Precisa 2200 C SCS), shaped into balls by hand and spoon, and reweighed before steaming. The meatballs were steamed for 20 minutes and then boiled at 100 °C for 5 minutes, or until they floated to the surface. After boiling, they were cooled in cold water for 1 minute. The plant-based meatballs with varying MKBF-to-BLP ratios were analyzed for cooking yield, protein content, and L* value. Protein content and L* were determined using the same methods and formulas applied for MKBF, while cooking yield was measured according to Kahraman et al. (2023). Equation 4 was used to determine the weight of uncooked and cooked plant-based meatballs.

Meanwhile, the plant-based meatballs from F0 to F4 were analyzed for WHC, texture profile analysis, TDF, and sensory characteristics. WHC was determined using centrifugal technique. A 2 g sample of plant-based meatballs was mixed with 10 ml of deionized water in a tube and centrifuged at 3,000 rpm for 20 minutes. After centrifugation, the released water was collected and measured. WHC (%) was calculated using Equation 5.

Texture profile analysis was performed using a texture analyzer (TA-XT Plus) equipped with a cylindrical probe (25 mm in diameter). The test conditions were set as follows: pre-test speed of 2.00 mm second^{-1}, test speed of 5.00 mm second^{-1}, post-test speed of 5.00 mm second^{-1}, and a pause time of 5 seconds. The texture parameters measured included hardness, chewiness, and springiness. For sample preparation, the meatballs were cut into cubes measuring 2 cm × 2 cm × 1 cm. Meanwhile, TDF was determined using the same method and formula applied for MKBF.

A multiple paired comparison test and a hedonic test were conducted to assess the sensory attributes of F0 to F4. Forty untrained panelists from Universitas Pelita Harapan, aged 17 to 21 years, participated in the sensory evaluation. In the multiple paired comparison test, plant-based meatballs F1 to F4 were compared with F0, which served as the reference. The attributes evaluated included beany taste, chewiness, hardness, and springiness. Panelists tasted the samples from left to right and determined whether the sample on the left was less or more than F0. The multiple paired comparison scale ranged from 1 (extremely less than F0) to 7 (extremely more than F0).

Panelists evaluated the acceptability of F0, F1, F2, F3, and F4 through a hedonic test. The attributes tested included beany taste, chewiness, hardness, springiness, and overall acceptance. The hedonic scale ranged from 1 (extremely dislike) to 7 (extremely like).

Data analysis

The study was conducted in two replications, each with two repetitions. Data were analyzed using SPSS version 25 with two-way ANOVA, followed by Duncan’s post-hoc test.

RESULTS AND DISCUSSION

Physicochemical characteristics of MKBF and BLP

The physicochemical characteristics of MKBF and BLP, including protein content, moisture content, L*, and TDF, were examined for their relevance in determining the functional properties of these ingredients in plant-based meatball formulations. Protein content plays a critical role in structure formation and contributes to overall texture when interacting with binders. Moisture content influences WHC and juiciness. TDF affects both textural integrity and nutritional value. L* was measured to assess the color attributes of the raw materials, which may influence the visual appeal of the final product.

Table 2 shows that MKBF contains more moisture than BLP, which can be attributed to the higher initial moisture content of the raw material. The initial moisture content of lentil seeds is approximately 12% (Morales-Herrejón et al., 2025), whereas raw KBF has a moisture content of 93.15% (Fitriani et al., 2024). This difference directly influences the moisture content of the processed raw materials. Table 2 shows that the protein content of BLP is higher (10.37±0.43%) than that of MKBF (1.28±0.12%). Fitriani et al. (2024) reported that the protein content of raw KBF is 1.2 g 100 g^{-1}, while brown lentils are known to have a high protein content ranging from 9.0 to 17.9 g 100 g^{-1} (Chelladurai and Erkinbaev, 2020). The higher protein content of BLP is therefore consistent with the protein-rich nature of its raw material. Dewan et al. (2024) further noted that boiling lentils and removing their seed coats increases protein content. Boiling and other heat treatments also reduce anti-nutritional properties such as tannins, which reduce amino acid availability in legumes by forming complexes with proteins and decreasing protein digestibility. The dehulling process additionally lowers tannin levels. Similar to brown lentils, banana flowers also contain tannins, which may explain the increase in protein content observed in MKBF compared to raw KBF. However, Vishwakarma et al. (2024) reported that protein content in food products may decrease upon boiling due to protein denaturation at high temperatures.

As shown in Table 2, the L* of MKBF is 50.01±0.47. Chaiwongsa et al. (2021) reported that banana flower blanched for 10 minutes in hot water at 100 °C (51.22±0.23) shows a higher degree of L* compared to blanching for 3 minutes (46.94±0.43) and 5 minutes (48.01±0.51). Table 2 shows that the L* value of BLP is 62.52±0.09.

Table 2. Physicochemical characteristics of MKBF and BLP

Physicochemical characteristics	MKBF	BLP
Moisture (%)	94.96±0.17^a	72.86±0.15^b
Protein (%)	1.28±0.12^a	10.37±0.43^b
L*	50.01±0.47^a	62.52±0.09^b
TDF (%)	3.81±0.04^a	6.21±0.05^b

Note: Values with different superscripts in the different columns have a significant difference at 5%

Gallego et al. (2020) analyzed the L* of lentil paste prepared using three different cooking methods: boiling, pressure, and microwave. Their study revealed that microwave cooking at 800 W for 30 minutes produced the highest L* (50.63±0.62), followed by boiling at 100 °C for 40 minutes (48.42±0.47), and pressure cooking at 8.7 psi for 15 minutes (47.24±0.43). The increase in L* values of legumes has been associated with high water absorption and pigment denaturation, particularly carotenoids. Microwave cooking led to greater water absorption and lower moisture content (73.57±0.62%) in the paste, which resulted in a higher L* value, followed by boiling (76.40±0.23%) and pressure cooking (78.79±0.43%).

BLP exhibits a higher L* than MKBF. This difference may be related to the inherent pigment composition of the raw materials. Lentils are naturally rich in carotenoids, particularly lutein and zeaxanthin, which give them a yellow–orange tone and a generally lighter base color. Heat processing can break down some of these pigments, but the loss is often accompanied by physical changes in the seed that increase light reflection, so the cooked product may still appear relatively bright. Banana flower, on the other hand, contains a considerable number of dark-colored compounds, such as anthocyanins, flavonoids, and tannins. Blanching may remove some of these through degradation or leaching, yet enough pigment remains to keep its color visibly deeper than that of lentil paste (Chaiwongsa et al., 2021).

The TDF content of MKBF is 3.81±0.04% (Table 2), indicating that most of the fiber in banana flowers is classified as crude fiber (Kodithuwakku and Abeysundara, 2025). Boiling does not affect the crude fiber content; it only degrades when exposed to strong acids or bases for 30 minutes or more. Raw lentils contain higher TDF levels (11.0 to 26.9%), with approximately 97% categorized as insoluble dietary fiber (Li et al., 2024). Cooking lentils increases both TDF and insoluble dietary fiber contents but decreases soluble dietary fiber due to fiber softening during cooking. In contrast, the dehulling process reduces TDF content, which likely explains the lower TDF value in BLP (6.21±0.05%). Overall, MKBF has a lower TDF content than BLP, as raw lentils (11.0 to 26.9%) naturally contain more TDF than raw MKBF (5.74%) (Carlin et al., 2025).

Determination of the optimum ratio of MKBF and BLP on the physicochemical characteristics

Variation in the ratio of MKBF and BLP showed a significant difference ($p < 0.05$) in cooking yield, protein content, and L* values, respectively, as shown in Table 3.

Cooking yield

Cooking yield is defined as the changes in food weight that occur during food preparation or cooking, resulting from moisture loss, evaporation, or water absorption (Ciobanu et al., 2025). Water absorption during boiling increases the weight of plant-based meatballs. Table 3 shows that with the increase of BLP in the ratio, there is a decrease in the cooking yield of plant-based meatballs, especially in ratios of 80:20, 70:30, 60:40, and 50:50. Plant-based meatballs with a 100:0 ratio do not contain BLP and therefore have a lower protein content compared to other ratios with BLP substitution. The increase in BLP in the ratio increases both the protein content and TDF of the plant-based meatball because, as seen in Table 2, BLP has higher

Table 3. Physicochemical characteristics of plant-based meatball with different ratios of MKBF and BLP

MKBF:BLP	Physicochemical characteristics		
	Cooking yield (%)	Protein content	L*
100:0	109.59±0.35^{b}	6.68±0.15^{a}	46.16±0.15^{a}
90:10	105.42±2.16^{ab}	7.60±0.38^{b}	49.57±0.15^{bc}
80:20	101.67±0.96^{a}	8.41±0.53^{c}	48.51±0.15^{abc}
70:30	102.43±1.90^{a}	9.43±0.04^{d}	51.00±0.15^{c}
60:40	103.88±4.12^{a}	9.64±0.76^{d}	47.52±0.15^{ab}
50:50	102.75±2.44^{a}	9.73±0.21^{d}	47.27±0.15^{ab}
40:60	105.68±2.81^{ab}	10.24±0.08^{d}	47.20±0.15^{ab}
30:70	105.53±1.77^{ab}	10.73±0.22^{de}	45.51±0.15^{a}

Note: Values are presented as mean±SD. Values within the same column followed by different superscript letters indicate significant differences ($p < 0.05$)

protein (10.37±0.43%) and TDF content (6.21±0.05%) compared to MKBF (1.28±0.12% and 3.81±0.04%, respectively).

Research conducted by Ball et al. (2021) using plant-based protein, such as pea, in cooked ground beef patties indicates that it will increase cooking yield due to its ability to retain more moisture. Additionally, a higher protein content further enhances cooking yield. Increasing TDF content will increase the cooking yield due to its ability to retain water and fat (Ciobanu et al., 2025). Results for cooking yield are higher than 100% because the final weight of the plant-based meatball is higher than the initial weight due to water absorbed into the plant-based meatball and trapped inside the plant-based meatball. The yield of plant-based meatballs likely results from the separation of components during cooking, as well as the effects of different formulations, cooking methods, and processing techniques in the studies.

Protein content

As shown in Table 3, plant-based meatballs with a higher BLP ratio will have a higher protein content. Plant-based meatballs with only MKBF (100:0) have the lowest protein content (6.68±0.15%). An increase in the BLP ratio will significantly increase the protein content of the plant-based meatball up to 70:30. Table 3 shows there was no significant difference between the 70:30 ratio and those with more BLP addition, indicating that 70:30 is the maximum addition of BLP to increase the protein content significantly.

Table 2 shows that MKBF contained 1.28±0.12% protein, while BLP contained 10.37±0.43%. Consequently, increasing the proportion of BLP led to higher protein content in the plant-based meatballs. According to Owusu-Apenten and Vieira (2022), a food product qualifies as a protein source if it provides at least 10% of the nutrient reference values (NRV) per 100 g, equivalent to 5 g of protein per 100 g, and is classified as high in protein if the amount is at least twice this threshold. Based on these criteria, plant-based meatballs formulated with MKBF and BLP at ratios of 100:0, 90:10, 80:20, 70:30, 60:40, and 50:50 can be regarded as protein sources, while the 40:60 and 30:70 ratios can be considered high in protein. However, plant-based protein sources generally provide less muscle growth potential and are limited in certain essential amino acids compared with animal-derived proteins. Therefore, incorporating diverse plant protein sources and achieving higher protein levels in plant-based products is necessary to support muscle growth comparable to that of animal proteins (López-Moreno and Kraselnik, 2025; Pandey et al., 2025).

*L**

Table 3 shows that the L* value increased with higher proportions of BLP up to 70:30 (51.00±0.15) compared to 100:0 (46.16±0.15), but decreased at 60:40 (47.52±0.15). However, no significant differences were observed among the other ratios. The initial increase in L* can be attributed to the lighter colour of BLP (62.52±0.09), as shown in Table 2, compared to the darker MKBF, resulting in a lighter appearance in the 70:30 formulation (Figure 1). The subsequent decrease may result from pigment interactions and partial pigment degradation during boiling, which can cause a duller tone despite BLP's high initial L*.

Determination of binder formulations on the physicochemical and sensory characteristics

Plant-based protein sources provide less muscle growth and are low in some essential

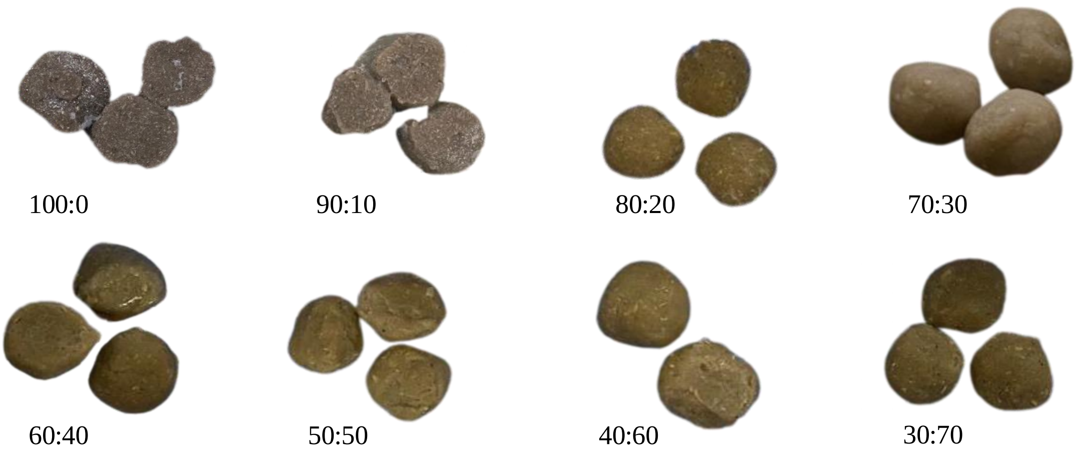

Figure 1. Plant-based meatballs with the variation ratio of MKBF and BLP

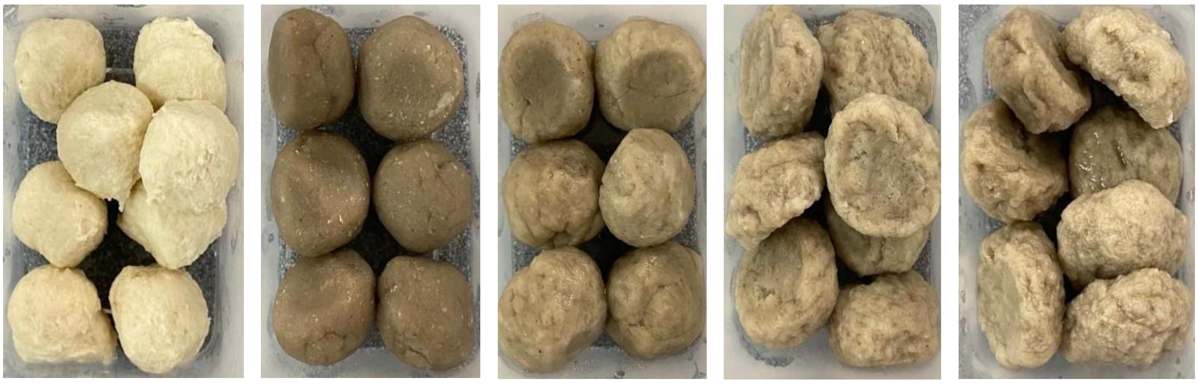

Figure 2. Plant-based meatballs, arranged from F0 on the left to F4 on the right

amino acids compared to animal proteins. Hence, incorporating a variety of plant-based protein sources and increasing the protein content in plant-based products is necessary to achieve muscle growth comparable to that of animal protein (López-Moreno and Kraselnik, 2025; Pandey et al., 2025). The optimum formulation ratio of MKBF and BLP was determined to be 40:60, as this combination produced a relatively high protein content (10.24±0.08%) in accordance with the standard suggested by Owusu-Apenten and Vieira (2022). Higher protein content contributes to a greater cooking yield due to improved moisture retention. The 40:60 ratio plant-based meatball exhibits the highest cooking yield (105.68±2.81%). Regarding color, this formulation yields an L* value of 47.20±0.15.

The subsequent stage of this study involved varying the binder to further enhance the functional properties of the formulation, specifically texture profile analysis, sensory characteristics, and WHC. The variation significantly affected ($p < 0.05$) the texture profile (hardness, chewiness, and springiness), WHC, and TDF content, as presented in Table 4 and illustrated in Figure 2, which shows the appearance of plant-based meatballs with different binder formulations.

WHC

WHC describes the ability of meat to retain water during processing and storage. It depends on the food's ability to bind water after protein denaturation and aggregation (Warner, 2023). As shown in Table 4, F0, which was formulated without additional WG, resulted in a lower WHC of 34.81±5.30% compared to F4, which contained the highest WG concentrations and had a WHC of 52.94±9.14%. The WHC of WG has been reported to range from 346.21 to 353.81% (Zhang et al., 2025), while ISP demonstrates a higher WHC of approximately 760% (Ma et al., 2022). WG tends to agglomerate and cross-link, forming a gluten network that traps water; thus, increasing WG concentration enhances WHC (Zhang et al., 2021). A higher WHC is associated with TDF, as dietary fiber can absorb water within the fiber matrix and help prevent structural degradation (Mazumder et al., 2023).

Texture profile analysis

The hardness value indicates the maximum force required to compress or deform food samples, like the compression between teeth, tongue, and upper ceiling of the mouth (Guiné et al., 2020). Chewiness refers to the energy required to chew solid food products until sufficiently softened for swallowing. Chewiness results from gumminess and springiness, equal to the product of hardness x cohesiveness x springiness. Meanwhile, springiness value shows the ability of food products to recover shape after compression and correlates with the rate at which the product can return to its original shape (Rahman et al., 2021).

As shown in Table 4, there is a significant increase of hardness in F2 (565.14±75.49 g) and F3 (563.76±71.57 g) compared to F1 (406.09±75.49 g). Hardness value has an inverse correlation with WHC. The higher the WHC, the more water the product retains. Thus, the product tends to be softer because water acts as a plasticizer, reducing the rigidity of the product. A higher WHC contributes to juicier and softer texture, while a lower WHC results in firmer, drier, and potentially harder products (Herz et al., 2021). These findings are in accordance with the results of WHC in this study, as illustrated in Table 4. F0 shows a lower WHC (34.81±5.30%) and a higher hardness value (622.81±89.25), indicating that the formulation retains less water, producing a drier and harder product. Meanwhile,

Table 4. Physicochemical characteristics of plant-based meatballs with different binder formulations

Binder formulations	Hardness (g)	Chewiness (Nmm)	Springiness (mm)	WHC (%)	TDF (%)
F0	622.81±89.25^{c}	464.94±56.30^{c}	0.90±0.0^{a}	34.81±5.30^{a}	2.24±0.07^{a}
F1	406.09±75.49^{a}	268.55±31.43^{a}	0.89±0.06^{a}	39.32±5.75^{a}	4.34±0.12^{b}
F2	565.14±75.49^{b}	356.82±75.49^{ab}	0.86±0.02^{a}	35.59±2.27^{a}	4.07±0.11^{c}
F3	563.76±71.57^{b}	386.57±59.40^{b}	0.87±0.03^{a}	42.20±4.68^{a}	3.99±0.04^{c}
F4	516.51±31.62^{ab}	353.28±21.66^{ab}	0.87±0.02^{a}	52.94±9.14^{a}	5.99±0.06^{d}

Note: Values are presented as mean±SD. Values with superscript letters in the same column indicate significant differences ($p < 0.05$)

F1 has a higher WHC (39.32±5.75%) than F0, which leads to lower hardness (406.09±75.49), indicating that the formulation retains more water, making the product softer and resulting in a chewier meatball. The use of ISP:WG in a 50:50 ratio could reduce the hardness of the product (Zhang et al., 2021). Conversely, increasing the WG ratio compared to ISP increases the hardness of the product and creates a more fibrous texture.

Table 4 shows that adding WG increases the chewiness of plant-based meatballs; however, compared to F0, the chewiness is likely reduced. F0 showed lower WHC than F4. Higher gluten levels in F4 bind more water within the gluten network, leaving less free water for other components, such as starch, resulting in a drier texture that feels less soft and elastic, and is less chewy (Younis et al., 2023).

In contrast to hardness and chewiness, different binder formulations showed no significant difference in the springiness value of plant-based meatballs ($p > 0.05$). Table 4 illustrates the decrease in springiness resulting from the addition of WG. According to Zhang et al. (2021), excess WG will lower the springiness of food products due to viscoelasticity. The viscoelasticity results from intramolecular disulfide bonds formed by α- and γ-gliadins found in WG.

TDF

As shown in Table 4, the increase of WG concentration in F1 to F4 showed a significant increase in TDF compared to F0. The soy protein in F0 is likely to contain a lower TDF than in other formulations. WG is a material that primarily consists of protein (Zhang et al., 2025). However, the primary source of WG, wheat, contains high TDF content ranging from 9 to 20% (Prasandi and Joye, 2020). Similarly, soy protein mainly consists of protein but still has TDF due to the primary source having 9 to 16.5% (Zhang et al., 2021). The base materials for plant-based meatballs with different binder formulations, which are MKBF and BLP, also contain TDF (3.81±0.04% and 6.21±0.05%, respectively), resulting in a higher TDF compared to F0.

According to Qi and Tester (2025), the source of dietary fiber products must contain a minimum of 3 g of dietary fiber per 100 g, while high-fiber products must contain 6 g per 100 g. As shown in Table 4, F0 does not qualify as a source of dietary fiber, while plant-based meatballs F1 (4.34±0.12%), F2 (4.07±0.11%), and F3 (3.99±0.04%) meet the criteria as sources of dietary fiber.

Sensory characteristics

In this study, F0 to F4 were evaluated for their sensory characteristics to achieve specific objectives. The multiple paired comparison test, using a commercial product as a reference, was employed to identify attribute differences across samples, such as taste or texture intensity. In contrast, the hedonic test measured overall liking and acceptability, complementing the analytical focus of the paired comparison (Kakati and Gogoi, 2025; Liu et al., 2025). Table 5 presents the results of the multiple comparison test, and Table 6 presents the results of the hedonic test.

As shown in Table 5, there were no significant differences between the F0 and all the plant-based meatballs with different binder formulations in terms of the beany taste. This indicates that the panelists perceived all plant-based meatball formulations as having a comparable beany taste to F0. Since F0 consists of soybean as its plant-based ingredient, all formulations in this study exhibited a similar level of beany taste. In terms of acceptance, F0, which is made from soybean and likely has a familiar taste for the panelists, combined with the presence of seasonings in the product, contributes to its higher degree of liking compared to F1 to F4 (Table 6). Meanwhile, F1 to F4 do not show any significant differences, as WG and ISP are tasteless and odorless,

Table 5. Results of multiple comparisons of plant-based meatballs with different binder formulations

Binder formulations	Beany taste	Hardness	Chewiness	Springiness
F0	4.00	4.00	4.00	4.00
F1	4.20±1.69	2.20±1.45*	2.17±1.55*	2.03±1.45*
F2	4.13±1.68	2.53±1.36*	2.80±1.42*	2.30±1.15*
F3	4.30±1.76	2.87±0.90*	3.03±1.16*	2.87±1.22*
F4	3.83±1.70	2.67±0.96*	3.03±1.30*	3.00±1.17*

Note: Values are presented as mean±SD, with * in the same column indicating significant differences ($p < 0.05$). Scale 1 (Extremely less than F0); Scale 4 (Comparable to F0); Scale 7 (Extremely more than F0)

Table 6. Results of hedonic test of plant-based meatballs with different binder formulations

Binder formulations	Beany taste	Hardness	Chewiness	Springiness	Overall acceptance
F0	$5.17±1.68^{b}$	$5.32±1.12^{a}$	$5.63±1.30^{d}$	$5.67±1.27^{d}$	$5.80±1.13^{d}$
F1	$3.63±1.16^{a}$	$2.77±1.01^{a}$	$2.67±1.30^{a}$	$2.50±1.17^{a}$	$2.93±0.83^{a}$
F2	$3.90±1.03^{a}$	$3.60±1.10^{bc}$	$3.57±1.22^{b}$	$3.47±1.14^{b}$	$3.83±1.15^{b}$
F3	$3.87±0.94^{a}$	$3.77±1.38^{b}$	$3.73±1.20^{b}$	$3.83±1.09^{b}$	$3.87±1.04^{b}$
F4	$4.10±0.99^{a}$	$4.27±1.08^{c}$	$4.57±1.04^{c}$	$4.57±1.13^{c}$	$4.43±1.04^{c}$

Note: Values are presented as mean±SD, with different superscripts in the same column indicating significant differences ($p < 0.05$). Scale 1 (Extremely dislike); Scale 4 (neutral); Scale 7 (Extremely like)

and therefore have no effect on the beany taste acceptance of the plant-based meatballs.

As shown in Table 5, plant-based meatballs treated with F1 (2.20±1.45), F2 (2.53±1.36), F3 (2.87±0.90), and F4 (2.67±0.96) exhibit significant differences in hardness. F1 to F4 were perceived as less hard by the panelists compared to F0 (4.00). These formulations contained binders such as ISP and/or WG, which can form a cohesive protein network upon hydration and heating. This structure might feel more uniform and compact, distributing the force applied during chewing and making the product perceived as less hard by the panelists. These results are also in line with the data presented in Table 4, showing that F0 has the highest hardness (622.81±89.25).

Table 6 displays all formulations perceived as less chewy compared to F0 (5.63±1.30). F3 and F4 have a higher concentration of WG, which leads to the formation of stronger protein matrices, resulting in a higher chewiness value compared to F1 and F2. The absence of WG and low amount of WG in F1 and F2, respectively, may have resulted in weaker gelation or protein matrix formation, leading to less cohesive and chewy texture. However, higher WHC in F4 creates a moister, cohesive texture, which panelists may perceive as less chewy and could also lead them to interpret chewiness differently (Gasparre and Rosell, 2023).

WG contributes to elasticity and springiness by forming a cohesive, elastic protein network during cooking (Schmid et al., 2022; Gasparre and Rosell, 2023). F4, with the highest concentration of WG, showed the closest value to F0 because the gluten provides a stronger and more elastic structure. Meanwhile, F1 and F2, which did not have or had lower WG, lacked sufficient elastic network formation, resulting in a less springy texture, as perceived by the panelists. ISP has good gel-forming properties, but it contributes more to firmness than springiness (Islam et al., 2023). F1, which relies more on ISP, may have been perceived as having denser texture, thus reducing its springiness.

The hedonic test in Table 6 shows that panelists tend to prefer plant-based meatballs with higher hardness, chewiness, and springiness values. Among the samples, F1 received the lowest liking scores for these attributes. The absence of gluten in F1 resulted in a crumbly texture, as gluten plays a crucial role in providing structure and elasticity. Thus, the product may have been perceived as less cohesive and with a more fragile texture (Schmid et al., 2022).

As presented in Table 6, F4 has higher acceptance compared to F1 to F3, as its hardness, chewiness, and springiness values were closest to F0 in the texture analysis. Panelists preferred plant-based meatballs with higher values for these texture attributes. Furthermore, F0 was seasoned with sugar, salt, and pepper, whereas this study applied salt, pepper, and garlic powder at varying concentrations. These differences in seasoning may also have contributed to variations in sensory perception and overall preference.

CONCLUSIONS

This study demonstrated the development of plant-based meatballs using a 40:60 ratio of MKBF to BLP, achieving a protein content of 10.24±0.08%, cooking yield of 105.68±2.81%, and L* of 47.20±0.15. Among the binder formulations, F4 (3% ISP + 25% WG) resulted in the highest WHC (52.94±9.14%) and TDF (5.99±0.06%), while also yielding the most favorable sensory attributes, particularly in hardness, chewiness, springiness, and overall acceptance. These findings highlight the potential of integrating underutilized local plant sources and optimized binder combinations to produce nutritionally rich, sensory-acceptable plant-based meat substitutes. Future research could explore pre-treatment methods, such as citric acid blanching, to improve L* and visual appeal.

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REFERENCES

Alsalman, F. B., Tulbek, M., Nickerson, M., & Ramaswamy, H. S. (2020). Evaluation of factors affecting aquafaba rheological and thermal properties. *LWT*, *132*, 109831. https://doi.org/10.1016/j.lwt.2020.109831

Amalia, L., Yuliana, N. D., Sugita, P., Arofah, D., Syafitri, U. D., Windarsih, A., … & Kusnandar, F. (2022). Volatile compounds, texture, and color characterization of meatballs made from beef, rat, wild boar, and their mixtures. *Heliyon*, *8*(10), e10882. https://doi.org/10.1016/j.heliyon.2022.e10882

Bakhsh, A., Lee, S. J., Lee, E. Y., Hwang, Y. H., & Joo, S. T. (2021). Traditional plant-based meat alternatives, current, and future perspective: A Review. *Journal of Agriculture & Life Science*, *55*(1), 1–11. https://doi.org/10.14397/jals.2021.55.1.1

Ball, J. J., Wyatt, R. P., Lambert, B. D., Smith, H. R., Reyes, T. M., & Sawyer, J. T. (2021). Influence of plant-based proteins on the fresh and cooked characteristics of ground beef patties. *Foods*, *10*(9), 1971. https://doi.org/10.3390/foods10091971

Bryant, C. J. (2022). Plant-based animal product alternatives are healthier and more environmentally sustainable than animal products. *Future Foods*, *6*, 100174. https://doi.org/10.1016/j.fufo.2022.100174

Carlin, J., Wang, N., Asavajaru, P., Polley, B., Kompany-Zareh, M., Bhowmik, P., … & Samaranayaka, A. (2025). Proximate composition, *in vitro* protein digestibility, and micronutrient density of commercial pea, faba bean, and lentil protein isolates and concentrates. *Sustainable Food Proteins*, *3*(2), e70006. https://doi.org/10.1002/sfp2.70006

Chaiwongsa, K., Charoenvitayavorakul, N., Pakasap, C., & Khuenpet, K. (2021). Effect of banana blossom substitution on quality characteristic of plant-based shiitake mushroom balls. *Asia-Pacific Journal of Science and Technology*, *26*(3), APST–26. https://doi.org/10.14456/apst.2021.52

Chelladurai, V., & Erkinbaev, C. (2020). Lentils. *Pulses: Processing and product development* (Fifth edit, pp. 129–143). Springer. http://dx.doi.org/10.1007/978-3-030-41376-7

Ciobanu, M.-M., Manoliu, D.-R., Ciobotaru, M. C., Flocea, E.-I., & Boișteanu, P.-C. (2025). Dietary fibres in processed meat: A review on nutritional enhancement, technological effects, sensory implications and consumer perception. *Foods*, *14*(9), 1459. https://doi.org/10.3390/foods14091459

Day, L., Cakebread, J. A., & Loveday, S. M. (2022). Food proteins from animals and plants: Differences in the nutritional and functional properties. *Trends in Food Science & Technology*, *119*, 428–442. https://doi.org/10.1016/j.tifs.2021.12.020

Devi, V. C., Devanampriyan, R., Kayethri, D., Sankari, R., Premalatha, J., Sathish Raam, R., & Mothil, S. (2025). Optimization and process validation of freeze-structured meat substitute using machine learning models. *Journal of Food Process Engineering*, *48*(3), e70071. https://doi.org/10.1111/jfpe.70071

Dewan, Md. F., Shams, S. -N. -Us, & Haque, M. A. (2024). Impact of processing on the bioactive compounds and antinutritional factors of lentil (*Lens culinaris* L.)—A review.

Legume Science, *6*(3), e253. https://doi.org/10.1002/leg3.253

Farida, F., & Rawiniwati, W. (2021). Agribusiness prospect of banana flowers and oyster mushrooms as raw materials of meatballs vegetarian. *Journal of Tropical Biodiversity*, *1*(3), 149–166. https://doi.org/10.59689/bio.v1i3.64

Fitriani, A., Toni, D. R., & Rahmadhia, S. N. (2024). Chemical characteristics of Kepok banana bud (*Musa Paradisiaca* Linn.) flakes with variations of mocaf flour. *Journal of Functional Food and Nutraceutical*, *5*(2), 97–105. https://doi.org/10.33555/jffn.v5i2.114

Gallego, M., Arnal, M., Barat, J. M., & Talens, P. (2020). Effect of cooking on protein digestion and antioxidant activity of different legume pastes. *Foods*, *10*(1), 47. https://doi.org/10.3390/foods10010047

Gasparre, N., & Rosell, C. M. (2023). Wheat gluten: A functional protein still challenging to replace in gluten-free cereal-based foods. *Cereal Chemistry*, *100*(2), 243–255. https://doi.org/10.1002/cche.10624

Guiné, R. P. F., Correia, P. M. R., Reis, C., & Florença, S. G. (2020). Evaluation of texture in jelly gums incorporating berries and aromatic plants. *Open Agriculture*, *5*(1), 450–461. https://doi.org/10.1515/opag-2020-0043

Haritha, V., & Bukya, A. (2025). Preparation and quality characterization of herbal nutritional powder. *International Journal for Research in Applied Science & Engineering Technology*, *13*(7), 241–249. https://doi.org/10.22214/ijraset.2025.72969

Herz, E., Herz, L., Dreher, J., Gibis, M., Ray, J., Pibarot, P., … & Weiss, J. (2021). Influencing factors on the ability to assemble a complex meat analogue using a soy-protein-binder. *Innovative Food Science & Emerging Technologies*, *73*, 102806. https://doi.org/10.1016/j.ifset.2021.102806

Islam, M., Huang, Y., Jain, P., Fan, B., Tong, L., & Wang, F. (2023). Enzymatic hydrolysis of soy protein to high moisture textured meat analogue with emphasis on antioxidant effects: As a tool to improve techno-functional property. *Biocatalysis and Agricultural Biotechnology*, *50*, 102700. https://doi.org/10.1016/j.bcab.2023.102700

Juhrich, L. C., Grosse, M., Mörlein, J., Bergmann, P., Zorn, H., & Gand, M. (2025). Nutritional and sensory properties of meat analogues: A current overview and future considerations. *Journal of Agricultural and Food Chemistry*, *73*(4), 2236–2248. https://doi.org/10.1021/acs.jafc.4c09414

Kahraman, E., Dağlioğlu, O., & Yilmaz, İ. (2023). Physicochemical and sensory characteristics of traditional kırklareli meatballs with added cowpea (*Vigna unguiculata*) flour. *Food Production, Processing and Nutrition*, *5*(1), 5. https://doi.org/10.1186/s43014-022-00120-1

Kakati, N., & Gogoi, B. (2025). A study of multiple comparison tests with imprecise and uncertain information. *Indian Journal of Science and Technology*, *18*(26), 2067–2074. https://doi.org/10.17485/IJST/v18i26.1547

Kartikaningsih, H., Yahya, Y., Yuniar, T., Jaziri, A. A., Zzaman, W., Kobun, R., & Huda, N. (2021). The nutritional value, bacterial count and sensory attributes of little tuna (*Euthynnus affinis*) floss incorporated with the banana blossom. *Potravinarstvo Slovak Journal of Food Sciences*, *15*, 846–857. https://doi.org/10.5219/1657

Khezerlou, A., Yekta, R., Abedi-Firoozjah, R., Alizadeh-Sani, M., & McClements, D. J. (2025). Advances in sensory and nutritional innovation for sustainable plant-based meat analogs: A comprehensive review. *Food Reviews International*, 1–26. https://doi.org/10.1080/87559129.2025.2520448

Kodithuwakku, H. T., & Abeysundara, P. De. A. (2025). Exploring the nutritional benefits of a ready-to-eat vegan sandwich filler developed with tender jackfruit, seaweed, banana blossom and soy flour: Formulation and quality analysis. *Food Chemistry Advances*, *8*, 101039. https://doi.org/10.1016/j.focha.2025.101039

Kyriakopoulou, K., Keppler, J. K., & van der Goot, A. J. (2021). Functionality of ingredients and additives in plant-based meat analogues. *Foods*, *10*(3), 600. https://doi.org/10.3390/foods10030600

Li, M., Xia, M., Imran, A., de Souza, T. S. P., Barrow, C., Dunshea, F., & Suleria, H. A. R. (2024). Nutritional value, phytochemical potential, and biological activities in lentils (*Lens culinaris* Medik.): A review. *Food*

Reviews International, *40*(7), 2024–2054. https://doi.org/10.1080/87559129.2023.2245073

Liu, X., Blumenthal, D., & Guénard-Lampron, V. (2025). From printability to palatability: A sensory and hedonic study of 3d-printed cereal- and legume-based products. *Innovative Food Science & Emerging Technologies*, *104*, 104078. https://doi.org/10.1016/j.ifset.2025.104078

López-Moreno, M., & Kraselnik, A. (2025). The impact of plant-based proteins on muscle mass and strength performance: A comprehensive review. *Current Nutrition Reports*, *14*(1), 37. https://doi.org/10.1007/s13668-025-00628-1

Ma, K. K., Grossmann, L., Nolden, A. A., McClements, D. J., & Kinchla, A. J. (2022). Functional and physical properties of commercial pulse proteins compared to soy derived protein. *Future Foods*, *6*, 100155. https://doi.org/10.1016/j.fufo.2022.100155

Maningat, C. C., Jeradechachai, T., & Buttshaw, M. R. (2022). Textured wheat and pea proteins for meat alternative applications. *Cereal Chemistry*, *99*(1), 37–66. https://doi.org/10.1002/cche.10503

Mazumder, Md., Sujintonniti, N., Chaum, P., Ketnawa, S., & Rawdkuen, S. (2023). Developments of plant-based emulsion-type sausage by using grey oyster mushrooms and chickpeas. *Foods*, *12*(8), 1564. https://doi.org/10.3390/foods12081564

Morales-Herrejón, Y. G., Márquez-Benavides, L., Herrera-Camacho, J., Cortés-Penagos, C. de J., & Yahuaca-Juárez, B. (2025). Lentil flour as an alternative source of protein. *Revista Mexicana de Ciencias Agrícolas*, *16*(3), e3696. https://doi.org/10.29312/remexca.v16i3.3696

Owusu-Apenten, R., & Vieira, E. (2022). Food labels. *Elementary food science* (Fifth edit, pp. 81–112). Springer. https://doi.org/10.1007/978-3-030-65433-7

Pandey, A., Pearlman, M., Bonnes, S. L., & Nour, S. I. (2025). Can we maintain muscle mass on a plant-based diet? *Current Nutrition Reports*, *14*(1), 16. https://doi.org/10.1007/s13668-024-00594-0

Prakash, S., Gaiani, C., & Bhandari, B. R. (2023). Plant-based food as a sustainable source of food for the future. *Engineering Plant-Based Food Systems* (First edit, pp. 1–12). Elsevier. https://doi.org/10.1016/B978-0-323-89842-3.00005-1

Prasandi, V. P. N., & Joye, I. J. (2020). Dietary fibre from whole grains and their benefits on metabolic health. *Nutrients*, *12*(10), 3045. https://doi.org/10.3390/nu12103045

Qi, X., & Tester, R. F. (2025). Dietary fibre for health and gastrointestinal therapeutic applications: A review. *Food Science and Engineering*, *6*(2), 246–260. https://doi.org/10.37256/fse.6220256243

Rahman, M. S., Al-Attabi, Z. H., Al-Habsi, N., & Al-Khusaibi, M. (2021). Measurement of instrumental texture profile analysis (TPA) of foods. *Techniques to Measure Food Safety and Quality* (First edit, pp. 427–465). Springer International Publishing. https://doi.org/10.1007/978-3-030-68636-9_17

Richirose, R., & Soedirga, L. C. (2023). Utilization of cassava-jicama composite flour in making gluten-free biscuits with different types of fats. *Caraka Tani: Journal of Sustainable Agriculture*, *38*(2), 244–259. https://doi.org/10.20961/carakatani.v38i2.71993

Schmid, E. M., Farahnaky, A., Adhikari, B., & Torley, P. J. (2022). High moisture extrusion cooking of meat analogs: A review of mechanisms of protein texturization. *Comprehensive Reviews in Food Science and Food Safety*, *21*(6), 4573–4609. https://doi.org/10.1111/1541-4337.13030

Sonmezler, D., Sumnu, G., & Sahin, S. (2025). Utilizing lentil proteins and flours for sustainable encapsulation and techno-functional applications in food technology. *Legume Science*, *7*(3), e70040. https://doi.org/10.1002/leg3.70040

Thagunnaa, B., Kandelb, K., & Lamichhanec, B. (2023). Banana blossom: Nutritional value, health benefits and its utilization. *Reviews in Food and Agriculture*, *4*(2), 66–70. http://dx.doi.org/10.26480/rfna.02.2023.66.70

Tiven, N. C., & Simanjorang, T. M. (2025). Chemical characteristic of beef meatball substituted by tuna (*Thunnus* sp.) meat. *AIP Conference Proceedings*, *3206*, 030008. https://doi.org/10.1063/5.0259786

Vishwakarma, S., Kulshrestha, R., & Tiwari, S. (2024). Cooking methods and their implications in the preservation of food nutrients and health benefits. *Traditional foods: The reinvented superfoods* (First edit, pp. 245–263). Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-72757-3_12

Wahab, N. B. A., Ismail, S. N., & Abidin, M. H. S. Z. (2020). Physicochemical and sensory characteristics of banana blossom nuggets. *International Journal of Research and Innovation Management*, *6*(1), 56–66. http://dx.doi.org/10.13140/RG.2.2.16759.64161

Warner, R. D. (2023). The eating quality of meat: IV—water holding capacity and juiciness. *Lawrie's meat science* (First edit, pp. 457–508). Elsevier. http://dx.doi.org/10.1016/B978-0-08-100694-8.00014-5

Widati, A. S., Rosyidi, D., Radiati, L. E., & Nursyam, H. (2021). The effect of seaweed (*Eucheuma cottonii*) flour addition on physicochemical and sensory characteristics of an Indonesian-style beef meatball. *International Journal of Food Studies*, *10*(3), 112–120. https://doi.org/10.7455/ijfs/10.si.2021.a9

Xavier, J. R., Shashikumar, S. H., Vats, D., & Chauhan, O. P. (2025). Future trends in plant-based meat: Consumer perception, market growth and health benefits. *Future Foods*, *11*, 100551. https://doi.org/10.1016/j.fufo.2025.100551

Yie, L. J., Khalid, N. I., & Ismail-Fitry, M. R. (2023). Quality evaluation of buffalo meatballs produced at different comminution process temperatures. *Malaysian Journal of Fundamental and Applied Sciences*, *19*(4), 573–582. https://doi.org/10.11113/mjfas.v19n4.2946

Younis, K., Ashfaq, A., Ahmad, A., Anjum, Z., & Yousuf, O. (2023). A critical review focusing the effect of ingredients on the textural properties of plant-based meat products. *Journal of Texture Studies*, *54*(3), 365–382. https://doi.org/10.1111/jtxs.12704

Yuan, X., Jiang, W., Zhang, D., Liu, H., & Sun, B. (2021). Textural, sensory and volatile compounds analyses in formulations of sausages analogue elaborated with edible mushrooms and soy protein isolate as meat substitute. *Foods*, *11*(1), 52. https://doi.org/10.3390/foods11010052

Zhang, L., Wang, Z., Gao, H., Zeng, J., Song, M., & Xu, J. (2025). Effect of wheat gluten on the quality of corn steamed bread prepared by modified corn flour and its frozen storage stability. *Food Measure*, *19*, 5886–5897. https://doi.org/10.1007/s11694-025-03361-z

Zhang, T., Dou, W., Zhang, X., Zhao, Y., Zhang, Y., Jiang, L., & Sui, X. (2021). The development history and recent updates on soy protein-based meat alternatives. *Trends in Food Science & Technology*, *109*, 702–710. https://doi.org/10.1016/j.tifs.2021.01.060